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Effect Modification of the Rice Technology Package to Improve Production Gripped Iron

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ABSTRACT

Rice is an important food crop in the world's second after wheat and estimated rice demand in 2015 reached 55.8 million Mg. Ministry of health stated that approximately 100 million people in Indonesia are suffer micronutrient deficiencies (*iron and iodine*), because they cannot afford to buy nutritious food but rely solely on the nutritional intake of rice. This study aimed to get the rice technology package to increase rice production that gripped the iron. This study consisted of two experiments which were test technology package with sri cultivation system and test modification technology packet with conventional cropping system. The experiment was arranged in a factorial with a completely randomized design and three replications. The experiments were conducted from May to October 2012 in Koto Baru of Dharmasraya District, West Sumatra. In rice cultivation gripped Fe^{2+} with the system rice intensificatin (SRI). The results showed thta the best package technology was the combination of: Krueng Aceh + peat soil (saphrict) 20 Mg ha^{-1} + square (10 × 10) × 30 cm with one seed per hole (age 10 days) + 5.0 mg kg^{-1} auxin. In this package technology, production of milled rice was 7.06 Mg ha^{-1}, while the iron content in rice grain varieties Krueng Aceh and Tukad Balian were 31.44 mg kg^{-1} and 34.99 mg kg^{-1}, respectively.

***Keywords*:** Auxin, Fe^{2+}, rice package technology

INTRODUCTION

Rice is a second important food crop in the world's after wheat. Rice demand in the year 2015 reached and estimated 55.8 million Mg approximately. In 1985, Indonesia's rice production was less than 49.03 million Mg of paddy. Since then, various efforts have been done to increase rice production so that in the year 2009 reached 64.84 million Mg of paddy, this was done in order to increase the income and welfare of the community and to improve national food security (Yayock *et al.*1997; Amang and Sawit 1999; Anonymous 2012). In the year 2005 there was a deficit of 4.21 million Mg of rice and it was fulfilled through imports. Besides the government was also active in the expansion and intensification program, it was not only in dry land but also in upland rice fields (Bilman 2008; Utama 2010a).

To increase the production of rice, a new potential land was opening in Dharmasraya with area more than 2.691 ha (Anonymous 2007), which was influenced by the high solubility of Fe^{2+} and Al^{3+} (Utama 2010a; Sunadi *et al*. 2010). The land was spread over 4 districts as follows: (1) Sungai Rumbai 41 ha, (2) Koto Baru 1.196 ha; Sitiung 718 ha, and (4) Pulau Punjung 818 ha. The average productivityof rice was only 2.2-2.5 Mg ha^{-1} (Anonymous 2007), while the current national rice production reached more than 4.75 Mg ha^{-1} (Bilman 2008; Sunadi *et al*. 2006).

Levels of ion ferrous are high as a result of flooded led to a reduction of Fe^{3+} to Fe^{2+}, that often related to low soil fertility (Sahrawat 2004; Sunadi *et al*. 2010), which causes inhibition of plant growth, especially for varieties that are susceptible to nutrient stress (Ma 2000; Rengel 2000; Utama *et al*. 2009; Utama 2010b; Noor *et al*. 2012).

High levels of dissolved Fe^{2+} in the new opening field result in harvest in the rice grains with a high iron content by natural bio-fortification methods. Increased levels of iron uptake by plants can be done by application the plant growth regulators auxin, due to its ability to manipulate the power of Source-Sink, thereby increasing the absorption of iron in rice grains (Hopkins 1995; Yang *et al*. 2002).

Data from the Ministry of Health showed that about 100 millions Indonesian population suffer from micronutrient deficiencies (iron and iodine) because of low ability to buy nutritious food and only rely on the rice nutrition (Finesso 2012; Anonymous 2012). Deficiency of iron (Fe) in children will cause anemia, recurrent infections, low intelligence, emotional distress, as well as permanent brain damage. According to WHO (2000), nearly 3 billions people in the world experience the micronutrient deficiency, whereas in-Indonesia account for about 30-60% especially children under five and pregnant women. Natural bio-fortification methods in which growing rice in a new opening paddy fields with high dissolved iron is potential to be utilized, to prevent iron deficiency in children and pregnant women.

Serious problems, on wetland rice cultivation in the new opening is a low productivity of the land due to limited technology and the cultivation of rice varieties tolerant to environmental stresses (Utama *et al*. 2009; Sunadi *et al*. 2010; Noor *et al*. 2012). To increase rice production wigh high iron contents, the new opening wetland program to improve rice productivity with multi technology packages were needed.

MATERIALS AND METHODS

Study Site

Research was conducted in the new opening paddy field, in Koto Baru Sitiung I, Dharmasraya District, West Sumatra, Indonesia and Laboratory "Kopertis" Region X, from May to October 2012. This study consisted of two experiments in parallel, namely: test technology package with sri cultivation system, and test modification technology package with conventional cropping system. New opening wetlands had a high level of dissolved Fe^{2+} (104.69 mg kg^{-1}) and other characteristics are presented at Table 1.

Research Design

Experiment 1. Test Technology Package with SRI Cultivation System

Experiments were arranged by a Completely Randomized Design, factorial with three replications. The first factor was rice varieties, namely: V_1 = Krueng Aceh; V_2 = IR36, and V_3 = Tukad Balian. The second factor was growth regulators, namely: Z_0 = 0.0 mg kg^{-1} auxin, and Z_1 = 5.0 mg kg^{-1} auxin. Package technology used in these experiments were: peat soil (saphrict) 20 Mg ha^{-1} + plant spacing (10 ×10 cm) x 30 cm with one seed per hole, age 10 days (Utama *et al*. 2009; Sunadi *et al*. 2010; Haryoko *et al*. 2012).

Experiment 2. Test Modification Technology Package with Conventional Cropping System

Experiments were arranged by a Completely Randomized Design, in a factorial with three replications. The first factor was rice varieties, namely: V_1 = Krueng Aceh; V_2 = IR36, and V_3 = Tukad Balian. The second factor was growth regulators, namely: Z_0 = 0.0 mg kg^{-1} auxin, and Z_1 = 5.0 mg kg^{-1} auxin. Package technology used in these experiments were: peat soil (saphrict) 20 Mg ha^{-1} + plant spacing (10 ×10 cm) × 30 cm with two seeds per hole, age 21 days.

Before germinating, rice seeds were immersed in the deltametrin solution, with the concentration of 3 g L^{-1} for 20 minutes, after that it was rinsed thoroughly and soaked for 24 hours. Flooded rice field were watered for 7 days, then it was added by a peat soil as much as 20 Mg ha^{-1} as a source of organic material. The amelioran was applied to soil as deep as 25-30 cm. The plot experiments with size 2.5 × 1.5 meters were created. Then, the rice field was incubated for 2 weeks. After that, it had reprocessed and continued to rake up and finally the land was ready for planting. In experiments with System Rice Intensification (SRI) system, seedlings were planted at the age of 10 days with one seedling per planting hole with a spacing square (10 × 10 cm) × 30 cm. Meanwhile, on a trial modification and conventional cropping system seedling were planted at 21 days with two seeds per planting hole. Auxin treatment was applied seedling one week after planting until the flowering plants phase by spraying it into the leaves of rice plants.

Type of fertilizers given in the early planting were Urea 1/3 dose, SP 36 and KCl. Further 1/3 dose of urea was applied at age 6 weeks plantation and 1/3 dose was applied at the generative phase. Weeding was done at the age of 2 and 6 weeks after transplanting. Watering was done intermediates, and stagnant water when primordial phase. Harvesting was done after the leaves had turned yellow up to 80% of the total population and grain on the panicles were whiter.

Statistical Analysis

All data were statistically analyzed by analysis of variance (ANOVA). Comparisons among means were analyzed by using Tukey test calculated at $P< 0.05$.

Table 1. Physical and chemical characteristics of Ultisols soil in Koto Baru Sitiung I of Dharmasraya District.

Soil Characteristic	Unit	Value	Criteria
Texture			
Sand	%	17.86	-
Silt	%	50.85	-
Clay	%	31.25	-
Class		Clay	-
Depth	cm	0-20	-
Bulk density		1.08	-
pH H_2O	-	5.07	sour
Organic Matter	-	2.56	-
Organic-C	%	1.49	low
Total-N	%	0.11	low
C/N ratio		12.04	medium
Available P (Bray 2)	mg kg^{-1}	3.29	very low
Arrangement of cations			
K^+	mol kg^{-1}	0.05	low
Na	mol kg^{-1}	0.13	low
Mg	mol kg^{-1}	0.20	very low
Ca	mol kg^{-1}	0.08	very low
		$\sum$ = 0.46	
CEC	mol kg^{-1}	14.93	low
Base saturated	%	3.08	very low
Exchangeable Acidity			
Al^{3+}	mg kg^{-1}	4.78	medium
H^+	mg kg^{-1}	0.87	-
Fe available (Fe^{2+})	mg kg^{-1}	104.69	high
Air dry water content	%	20	

Source: Utama *et al*. (2012).

RESULTS AND DISCUSSION

The results of the analysis of the physical and chemical characteristics of the soil used in this experiment, showed low of organic matter content, total-N, available P and K-dd. Likewise, Al saturation was medium and it had a potential to contribute to H^+ ions in the soil solution so that the low soil acidity (Table 1). These indicators show that the wetland was needed additional ameliorant. Ameliorant added in this experiment was the saphrict types of peat soils origined from Padang Pariaman.

In the rice flooded fields, the concentration of dissolved iron varied from 0.1 mg kg^{-1} to 600 mg kg^{-1}, this happens shortly after flooding. In acid soils with organic matter content and heavy oxides, it can produce ferrous iron concentration to the level of highly toxic, especially the ultisol, oxisol, acid sulfate, and peat tidal areas (Barchia 2009; Audebert and Sahrawat 2000; Becker and Asch 2005; Dorlodot *et al*. 2005).

Table 1 shows high levels of dissolved Fe^{2+} on the new paddy field, it had affected the growth of all cultivated rice varieties. The growth of rice varieties show the diversity for all parameters (Tables 2 and 3). The diversity, occured because each variety had a different genetic potential, in response to the environment, especially iron stress. Nutrient status of the plant will affect the level of tolerance to iron toxicity. The increased solubility of hydrogen sulfide and ferrous sulfide due to flooding will affect the ability of roots to oxidize, so the plants become more sensitive to iron poisoning.

Tables 2 and 3 show the different growth response of each rice variety to iron stress, which was cultivated by SRI system and the modified conventional system. All varieties which were cultivated in paddy fields gripped the iron, showed differences in tillers number that can be seen in Figure 1 and 2. It was clear the difference tillers number in the cultivation of sri system, modified conventional system and cultivation by local farmers with conventional systems.

Table 2. The tillers number, panicles number, panicle length, spikelet number, grain number, 1,000 grain weight and grain weight ha^{-1} in SRI cultivation.

Concentration Auxin	Rice Cultivars		
	Krueng Aceh	IR36	Tukad Balian
		Tillers Number	
0.0 ppm	75.41 a	57.41 b	52.82 b
5.0 ppm	83.94 a	82.94 a	76.43 a
		Panicles Number	
0.0 ppm	68.73 b	54.35 c	63.68 b
5.0 ppm	76.84 a	63.11 b	68.37 b
		Panicle Length	
0.0 ppm	23.06 c	22.47 c	40.08 a
5.0 ppm	31.68 b	25.16 c	43.52 a
		Spikelet Number	
0.0 ppm	9.92 ab	9.48 ab	9.54 ab
5.0 ppm	11.24 a	8.82 b	9.84 ab
		Grain Number	
0.0 ppm	2.926.8 a	2302.9 b	2986.3 a
5.0 ppm	3.124.6 a	2425.5 b	3012.4 a
		1.000 Grain Weight (g)	
0.0 ppm	28.84 a	25.14 d	26.70 bc
5.0 ppm	29.02 a	25.86 cd	27.20 b
		Grain Weight (Mg ha^{-1})	
0.0 ppm	6.18 ab	4.94 bc	5.65 bc
5.0 ppm	7.06 a	4.85 c	5.67 bc

Mean followed by different letters on the same variables in each treatment showed significantly different at 5% level by Tukey test.

Figure 1 shows great number of tillers. This was due to the use of young seedlings age of 10 days, with four seedlings per hill at a spacing (10 × 10) × 30 cm that could encourage intensive vegetative growth, since plants did not compete the absorption of nutrients and light, so the photosynthetic activity could be maximized. Carbohydrates were the result of photosynthesis, that were utilized to produce rice tillering.

Different response of these rice varieties led to growing diversity in the observed parameters such as tillers number, panicles number, panicle length, spikelet number, grain number, 1.000 grain weight, and grain weight ha^{-1} in cultivation with multi-packet technology with SRI system and modification of conventional systems (Tables 2 and 3).

Tillers number of each variety were between 52.82 to 83.94 tillers per hill, while the spikelet number of some rice varieties ranged from 8.82-11.24. The highest spikelet number (11.24) was produced by Krueng Aceh variety, while the lowest (98.82) was produced by IR36 variety. The highest grain number (3124.6 grain), 1.000 grain weight (29.02 g) and grain weight (7.06 Mg ha^{-1}) was found in the combination treatment between varieties Krueng Aceh and 5.0 mg kg^{-1} auxin (Table 2). Similarly, the modified cultivation with conventional systems, the highest paddy production was 5.67 Mg ha^{-1} (Table 3) and this production was much higher than the production of local farmers (2.2-2.5 Mg ha^{-1}) (Anonymous 2007).

High levels of dissolved Fe^{2+} and Al^{3+}, affected the growth of all crops cultivated (Delhaize and Ryan 1995; Sahrawat 2004; Utama 2008). The growth of paddy rice varieties on new openings showed a high diversity on tillers number, leaves number, canopy dry weight, root dry weight, panicles number, panicle length, spikelet number and grain weight. Diversity occured because each variety had a different genetic potential and was growed under environmental stress, especially dissolved Fe^{2+} and Al^{3+} (Sunadi *et al.* 2010; Utama *et al.* 2012). The plant growth and production were good because Krueng Aceh varieties, IR36 and Tukad Balian were tolerant varieties that could adapt well to nutrient stress as shown in Tables 2 and 3.

The hydrogen sulfide onset and ferrous sulfide in flooded rice fields were very reductive, contributed to the onset of iron toxicity in lowland rice. The higher solubility of hydrogen sulfide and

Table 3. The tillers number, panicles number, panicle length, spikelet number, grain number, 1,000 grain weight, and grain weight ha^{-1} in the conventional system of cultivation with modifications.

Concentration Auxin	Rice cultivars		
	Krueng Aceh	IR36	Tukad Balian
		Tillers Number	
0.0 ppm	61.08 ab	54.32 bc	57.56 bc
5.0 ppm	67.17 a	53.49 c	65.64 a
		Panicle Number	
0.0 ppm	49.14 abc	41.37 d	43.82 cd
5.0 ppm	53.46 a	45.96 bcd	51.41 ab
		Panicle Length	
0.0 ppm	20.75 d	19.81 d	32.85 b
5.0 ppm	26.64 c	21.92 d	39.36 a
		Spikelet Number	
0.0 ppm	7.83 ab	7.06 b	8.32 ab
5.0 ppm	9.57 a	8.17 ab	8.17 ab
		Grain Number	
0.0 ppm	2300.7 bc	2024.8 c	2459.2 abc
5.0 ppm	2934.7 a	2172.2 bc	2719.5 ab
		1000 Grain Weight (g)	
0.0 ppm	26.04 a	23.88 a	24.13 a
5.0 ppm	28.69 a	26.72 a	27.08 a
		Grain Weight (Mg ha^{-1})	
0.0 ppm	4.35 ab	3.89 b	4.12 b
5.0 ppm	5.67 a	3.96 b	4.94 ab

Mean followed by different letters on the same variables in each treatment showed significantly different at 5% level by Tukey test.

Table 4. Iron content in rice grain varieties Krueng Aceh and Tukad Balian treated with growth regulators.

Concentration Auxin	Rice cultivars	
	Krueng Aceh	Tukad Balian
	Iron content (mg kg^{-1}) rice grains	
0.0 ppm	21.47 ab	11.97 b
5.0 ppm	31.44 ab	34.99 a

Mean followed by different letters on the same variables in each treatment showed significantly different at 5% level by Tukey test.

ferrous sulfide affected the ability of roots to oxidize, so the plants became more sensitive to iron toxicity (Barchia 2009; Audebert and Sahrawat 2000; Becker and Asch (2005) Each rice variety had a different response to iron toxicity (Tables 2, 3, 4 and Figures 1, 2).

In Tables 2, 3 and 4 most of the parameters, showed better growth with auxin than without auxin treatment. This was presumably because the plants were able to adapt to acquire nutrients in sufficient quantities (Utama 2010a; Utama *et al*. 2012), but the plant still required a mechanism for the growth regulation. Material of plant growth regulators were needed by the plant in very small amounts in the mg kg^{-1} concentration (Salisbury and Ross 1992; Peng and Yamauchi 1993). The growing arrangement related to the ability of plants to manipulate Source-Sink, which was needed to determine when a part of the plant will continue to grow and the other part will stop growing (Hopkins 1995; Yang *et al*. 2002).

Iron poisoning can occur if the plants accumulate iron in high concentrations, it is associated with high levels of ferrous iron in the soil solution. Critical limit of iron concentration in soil varies depended on the pH of the soil, about 100 mg kg^{-1} at pH 3.7 and 300 mg kg^{-1} at pH 5.0 (Fageria *et al*. 2008; Audebert and Sahrawat 2000). Specific symptoms of iron poisoning will arise when the iron

A B

Figure 1. Growth of rice seedlings in a clump at a distance [square (10 × 10) × 30 cm] in cultivation with multi-packet technology (A= before cutting and B = after cutting).

A B

Figure 2. Seedling growth of the groups [system square (10 × 10) × 30 cm] with 2 seeds per planting point (age 21 days), modification of the conventional cultivation system (A) and growth of rice seedlings in conventional cultivation by farmers around the study sites with spacing of 25 × 25 cm (5 seeds) using a 21-day old seedlings (B).

content in plants more than 300 mg kg^{-1}. High concentrations of iron in the soil solution, will inhibit the uptake of other nutrients, such as phosphorus and potassium.

Figure 2B shows, the increase tiller was very limited even less likely to increase, it was due to the local farmers used old seeds (aged 21 days) that were not tolerant to Fe^{2+} stress and no additional package technology to improve growth and production. In susceptible rice varieties, nutrient stress will cause growth inhibition of plant height, tillers number, leaf chlorophyl, and root production (Sahrawat 2004; Fageria *et al*. 2008). In contrast, in Figure 1A, 1B and 2A, the rice varieties used were tolerant to Fe^{2+} stress (Sunadi *et al*. 2010; Utama *et al*. 2012), and were combined with some technology packages included the use of plant growth regulators so that the plant was still capable to have high productivity even in gripped conditions (Tables 2, 3 and 4), due to the nature of the production plant physiology in associated to Fe stress tolerance.

Laboratory analysis results showed that grain rice varieties of Krueng Aceh and Tukad Balian with auxin treatment were able to increase the iron uptake. Krueng Aceh variety with 5.0 mg kg^{-1} auxin increased iron levels by 46%, whereas Tukad Balian variety an increased by 92% (Table 3). In the market, iron content (Fe) of rice generally was less than 12 mg kg^{-1}, while the Krueng Aceh and Tukad Balian were 31.44 and 34.99 mg kg^{-1}, respectively or 3-fold higher. On some rice varieties, which was published by Finesso (2012) showed varying iron content, i.e. Cimelati (17.55 mg kg^{-1}), Gilirang (14.30 mg kg^{-1}), Bengawan Solo (13.11 mg kg^{-1}), Sintanur (12.26 mg kg^{-1}) and strain Unsoed (22-29 mg kg^{-1}). At the trial, plant breeders have used genetic engineering methods that are complicated and takes long time to increase iron levels in rice grain.

The highest iron contents in rice grain varieties of Krueng Aceh and Tukad Balian were because these varieties were tolerant to Fe stress (Sunadi *et al*. 2010: Utama *et al.* 2012). Dissolved Fe around rhizospher was absorbed by plants for growth and translocated to the rice grains. In addition, treatment of auxin manipulation also affected the strength of the Source-Sink mechanism (Hopkins 1995; Yang *et al.* 2002) in rice, which affected the growth and diffrensiation of Sink networks such as grains, so that increased the absorption of iron (Fe) in rice grains. While the rice varieties were sensitive to nutrient stress, high solubility of nutrients caused the poisoned rice plants, so the decline in production could even lead to crop failure (Sahrawat 2010; Noor *et al*. 2012).

CONCLUSIONS

In SRI system cultivation, the best combination technology package was a Krueng Aceh + peat soil (saphrict) 20 Mg ha^{-1} + square (10 × 10) × 30 cm + one seedling per planting point (age 10 days) + 5.0 mg kg^{-1} auxin, that was able to increase growth and production in the cultivation land high in Fe^{2+}. While, in the conventional system cultivation with modifications, the best combination technology package was a Krueng Aceh + peat soil (saphrict) 20 Mg ha^{-1} + square (10 × 10 cm) × 30 cm + two seeds per planting point, aged 21 days + 5.0 mg kg^{-1} auxin. The last technology package was capable to produce paddy of 5.67 Mg ha^{-1}.

The cultivation of paddy rice in the new field particularly in Koto Baru Dharmasraya was recommended to use a combination package of Krueng Aceh + peat soil (saphrict) 20 Mg ha^{-1} + square (10 x 10) × 30 cm + one seedling per planting point (age 10 days) + 5.0 mg kg^{-1} auxin, because it could increase production by 7.06 Mg ha^{-1} of paddy with high levels of iron in rice grains Krueng Aceh (31.44 mg kg^{-1}) and Tukad Balian (34.99 mg kg^{-1}).

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REFERENCES

Amang B dan MH Sawit. 1999. Kebijakan beras dan pangan nasional, pelajaran dari orde baru dan era reformasi. IPB, Bogor (in Indonesian).

Anonymous. 2007. Kabupaten Dharmasraya dalam angka. Bappeda Dharmasraya dan BPS, Sumbar (in Indonesian).

Anonymous. 2012. Padi berkadar besi tinggi dari kedelai, upaya mengatasi anemia. Kompas, 22 November 2012 (in Indonesian).

Audebert A and KL Sahrawat. 2000. Mechanisms for iron toxicity tolerance in lowland rice. *J Plant Nutr* 23: 1877-1885.

Barchia MF. 2009. Agroekosistem tanah mineral masam. UGM, Press. Yokyakarta (in Indonesian).

Becker M and F Asch. 2005. Iron toxicity in rice-condition and management concept. *J Plant Nutr Soil Sci*. 168: 558-573.

Bilman WS. 2008. Modifikasi lingkungan melalui sistem penanaman serta penambahan bahan organik dan zat pengatur tumbuh dalam upaya peningkatan produktifitas padi gogo (*Oryza sativa* L.). Disertasi, Unand. Padang (in Indonesian).

Delhaize E and PR Ryan. 1995. Aluminum toxicity and tolerance in plants. *Plant physiol*. 107: 315-321.

Dorlodot S, S Lutts, and P Bertin. 2005. Effect of ferrous iron toxicity on the growth and mineral competition of an interspecific rice. *J Plant Nutr*. 28: 1-20.

Haryoko W, Kasli, I. Suliansyah, A Syarif and TB Prasetyo. 2012. Toleransi beberapa varietas padi sawah gambut berkorelasi dengan kandungan asam fenolat. *J Agron Indon* 40: 112-118 (in Indonesian).

Hopkins WG. 1995. Introduction to Plant Physiology. The University of Western Ontario. John Wiley and Sons, INC.

Finesso GM. 2012. Mencari padi berzat besi tinggi, memanen matahari. Kompas, 12 Juni 2012 (in Indonesian).

Fageria NK, AB Santos, MPB Filho and CM Guimaraes. 2008. Iron toxicity in lowland rice. *J Plant Nutr* 31: 1676-1697.

Ma JF. 2000. Role of organic acids in detoxification of aluminum in higher plants. *Plant Cell Physiol* 41: 383-390.

Noor A, I Lubis, M Ghulamahdi, MA Chozin, K Anwarand and D. Wirnas. 2012. Pengaruh konsentrasi besi dalam larutan hara terhadap gejala keracunan besi dan pertumbuhan tanaman padi. *J Agron Indonesia* 40: 91-98

Peng XX and M Yamauchi. 1993. Ethylene production in rice bronzing leaves induced by ferrous iron. *Plant Soil* 149: 227-234.

Rengel Z. 2000. Mineral nutrition of crops, fundamental mechanisms and implications. Food production press, Binghamton.

Sahrawat KL. 2004. Iron toxicity in wetland rice and the role of other nutrients. *J Plant Nutr* 27: 1471-1504.

Sahrawat KL. 2010. Reducing iron toxicity in lowland rice with tolerant genotypes and plant nutrition. *J Plant Stress* 4:70-75.

Salisbury FB and CW Ross. 1992. Plant physiology. Fourth edition. Wadsworth, Belmont, California. 681 p.

Sunadi, M Kasim, A Syarif and N Akhir. 2006. Pertumbuhan dan hasil padi sawah dalam metode SRI dengan pengaturan jumlah bibit rumpun per rumpun sistem tanam satu-satu. *J Gakuryoku* 12: 120-123 (in Indonesian).

Sunadi, I Wahidi and MZH Utama. 2010. Penapisan varietas padi toleran cekaman Fe^{2+} pada sawah bukaan baru dari aspek agronomi dan fisiologi. *J Akta Agrosia* 13: 16-23 (in Indonesian).

Utama MZH. 2008. Mekanisme fisiologi toleransi cekaman aluminium pada spesies legum penutup tanah terhadap metabolisme Nitrat (NO_3^-), amonium (NH_4^+), dan nitrit (NO_2). *Bull Agron* 36: 175-179 (in Indonesian).

Utama MZH. 2010a. Penapisan varietas padi gogo toleran cekaman aluminium. *J Agron Indon* 38: 163-169 (in Indonesian).

Utama MZH. 2010b. Effect of NaCl-stress on metabolism of NO_3^-, NH_4^+ and NO_2^- at several rice varieties. *J Trop Soils* 15: 189-194. doi: 10.5400/jts.2010.15.3.189.

Utama MZH, W Haryoko, R Munir and Sunadi. 2009. Penapisan varietas padi toleran salinitas pada lahan rawa di Kabupaten Pesisir Selatan. *J Agron Indon* 37: 101-106 (in Indonesian).

Utama MZH, I Wahidi and Sunadi. 2012. Response of some rice cultivars seized with Fe^{2+} new opening paddy fields with multi package technology. *J Trop Soils* 17: 239-244. doi: 10.5400/jts.2012.17.3.239.

Yang J, S Peng, Z Zhang, Z Wang, RM Visperas, Q Zhuand and L Liu. 2002. Grain and dry matter yields and partitioning of assimilates in japonica/indica hybrid rice. *Crop Sci* 42: 766-772.

Yayock JY, G Lombin and JJ Owonuhi. 1997. Crop Science and production in warm climates. Mac Millan Intermediate Agriculture series. General of ochapa in Ozomi.